ULTRASONIC FIELD RECONSTRUCTION FROM OPTICAL INTERFEROMETRIC MEASUREMENTS

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INTRODUCTION

Acousto-optical measurement inside transparent media is a well known non invasive method for acoustic fields probing. The optical index variations induced by acoustic wave propagation in a liquid or transparent solid can be detected using several techniques: optical deflection, diffraction methods, etc ... Last year, X. Jia, G. Quentin and Laszlo Adler [1] described the ability of a interferometric detection technique to provide local and quantitative measurements of pressure fields in water as well as dilatational fields inside transparent solids. This method combines the acousto-optical effect with heterodyne interferometry. It measures the phase shift of a laser beam passing through an ultrasonic wave. The interferometric detection provides a local measurement and is sensitive not only to the amplitude but also to the phase of the acoustic wave. Finite amplitude waves in liquid, [1], bulk waves in solids [1] as well as guided waves (Rayleigh waves [2], Lamb waves [3] and Interface waves[4]) has been successfully detected using this method.

However, like most of the acousto-optical method, this method is limited to a two dimensionnal measurement. Because the laser beam integrates the pressure field along its path, the information in the beam direction is lost . The aim of this work is to recover the lost information using a well known technique in the field of x-ray inspections: the tomographic reconstruction from a set of projection of the pressure field. Reibold and al. [5] proposed a similar technique, using a classical Schlieren experimental set-up, in order to characterize continuous pressure fields radiated by transducers. This reconstruction procedure combined with the interferometric detection -suggested in this paper- allows one to map the very near (<1mm from the source) and transient field of immersed ultrasonic transducers in the plane parallel to the surface of the transducer.

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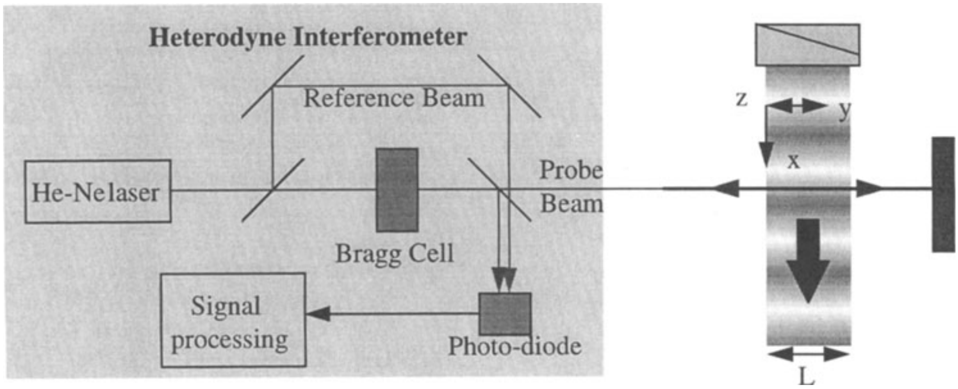

Figure 1: Interferometric detection of pressure field radiated from a transducer.

THE INTERFEROMETRIC METHOD

The principle of the interferometric method is described in figure 1. The optical phase shift of a laser beam induced by the pressure wave propagating in a fluid is measured using a heterodyne interferometer. The interference of the probe beam and a reference beam on a photo-diode produces a photo-current I:

$$I(t) = Io + (Io/2)\cos[\,\omega_b t + \nu(t) + \Phi_o] \,, \tag{1}$$

where Io is the optical intensity of the laser beam, Φ_o the static phase difference between the reference beam and the probe beam and ω_b is the bragg cell frequency. The so-called Raman-Nath parameter $\nu(t)$ is defined by:

$$\upsilon(t) = \frac{2\pi\kappa}{\lambda} \int_L p(x,y,z,t)\,dl \quad , \tag{2}$$

where λ is the optical wavelength, k is the acousto-optic coefficient of the fluid ad p the acoustical pressure. In most cases, the acoustic wave amplitude is low enough to ignore the beam deflection and the path L is a straight line. If the pressure field can be considered constant along the beam path (along the 0Z direction on figure 2) , then eq. 2 can be written:

$$\nu(t) = \frac{2\pi\, L}{\lambda}\ \kappa\ p(x,y,t)\,. \tag{3}$$

A broadband processing electronic device is used to extract the phase modulation $\nu(t)$ from the photo-current [5]. The final output current is a time dependent signal proportionnal to the average of the pressure along the laser-beam path. The sensitivity of the interferometric technique is 5 Pa/mV for a interaction length (width of the acoustic beam) of 10 mm and an He-Ne laser [1].

When the pressure field is not constant along the laser beam path, the measured value is an integrated value of the pressure field in as shown on picture 3. Let us consider the case of the field radiated into water by a transducer. In order to recover the amplitude anywhere in the cross section plane, a reconstruction technique based on a classical tomographic algorithm is applied. The pressure field is illuminated by a series of rays crossing the cross section plane at regular linear intervals. A set of ray integrals along certain lines is called a projection. The amplitude is measured either on the time signal for a given time or on the frequency spectra for a given frequency. This allows us to map the transient pressure field or the frequency response in the cross section plane. In order to obtain another projection, the transducer is rotated by some angle and the process is repeated (Figure 2).
These sets of projections, P(s,Θ), are then processed using the filtered back projection algorithm [7]. The pressure in the cross section plane p(x,y,t) is reconstructed using by filtering in the Fourier domain a back-projection of all the projections using the following expression :

$$p(x,y,t) = \int_{0}^{\pi} \int_{-\infty}^{\infty} \tilde{P}(R,\Theta)\, e^{i\,2\pi\, R(x\cos\Theta + y\sin\Theta)} |R|\, dR\, d\Theta \tag{4}$$

where

$$\tilde{P}(R,\Theta) = \int_{-\infty}^{+\infty} P(s,\Theta)\, e^{-i\,2\pi\, s.R} ds\,. \tag{5}$$

Because each projection is constructed from a set of single measurements, a discrete version of these integrals are used. This implies to chose the sampling rate in order to avoid aliasing problems during the reconstruction.

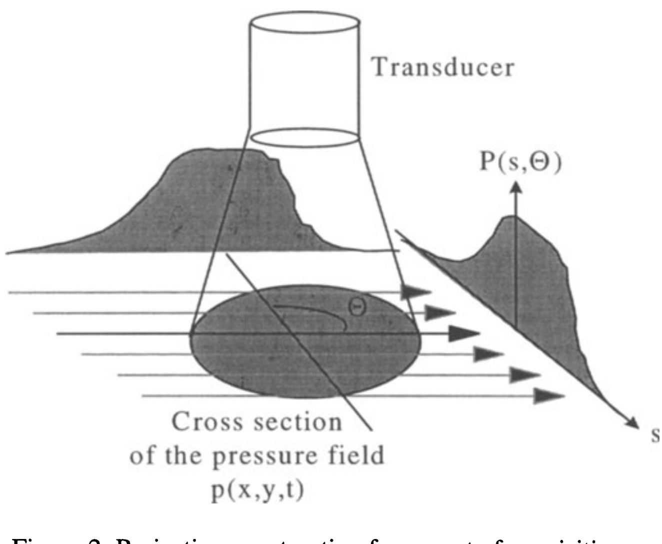

Figure 2: Projection construction from a set of acquisitions.

EXPERIMENTAL SET-UP AND RESULTS

The probe laser beam coming from the interferometer crosses back and forth, after reflection on a mirror, the acoustic field radiated by an immersed transducer. The transducer can be shifted and rotated about its axis using different step increments depending on the required sampling rate. The distance from the laser beam to the surface of the transducer can be as small as 0.2mm, allowing us to reconstruct the very near pressure field. The transducer is excited using a pulse generator. Acquisition of the time signals collected at the output of the interferometer is made on a digital oscilloscope. As previously said, the reconstruction is made either using the amplitude in the time domain -at a given time- or in the frequency domain after Fourier transform calculation -for a given frequency. The very near pressure field (z=0.5mm) radiated by two 0.5MHz broad-band panametrics transducers have been investigated. In each cases, the mapped area is 29mm*29mm. The translation step was 0.9mm and the rotation step was 5.65 degree. Consequently, the reconstructed field was mapped using a 32*32 points grid. Figure 3 shows the reconstructed pressure amplitude corresponding to two different times. The two lines appearing on the middle graph are believed to be the effect of the electrodes mass loading on the piezoelectric plate.
Figure 4 shows the reconstructed field amplitude for three frequencies close to the central frequency of the transducer. Different mode vibration patterns are seen.
Figure 5 shows the time response of a damaged transducer. In that case, the non-uniformity of the radiated pressure field is clearly seen after reconstruction. In order to check the validity of the method, these transient pressure fields are compared with the normal displacement of the transducer's surface in air using the interferometer in the classical normal displacement measurement configuration.

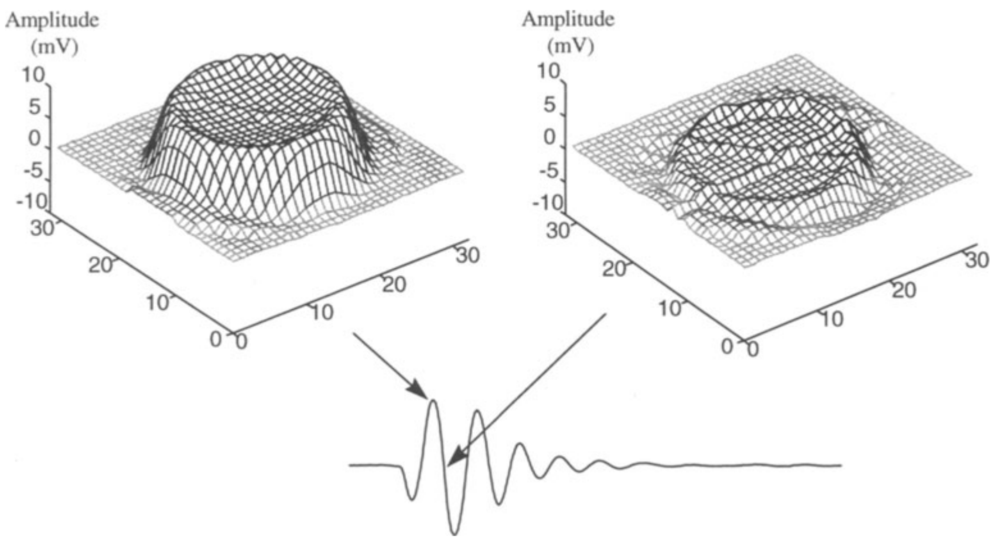

Figure 3: Transient pressure field of a 0.5MHz broadband transducer for two times selected on the waveform recorded for a projection. The reconstruction is made from measurements at z=0.2mm from the transducer surface.

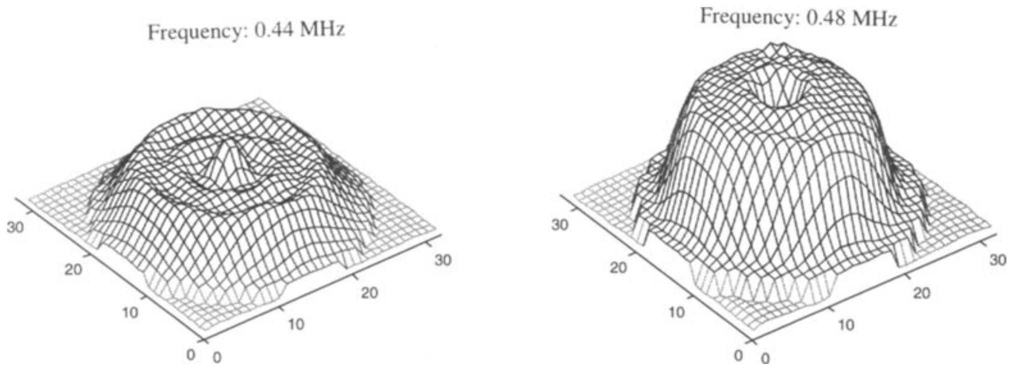

Figure 4: Reconstructed amplitude of the same transducer as fig.3 for 2 frequencies. The Fourier transform is performed on the time signals before reconstruction.

The same excitation pulse is used for the two measurement and two c-scan, very near radiated pressure field in water and normal displacement in air picked up at the same time, are displayed on figure 6. The amplitude are displayed in deciBel using a gray scale where the normalized values are the maximum amplitude in each cases. Despite two very different sampling rates, figure 6 shows a good agreement between the two measurement. This result shows the good quality and sensitivity of the very near field investigation made using the reconstruction technique.

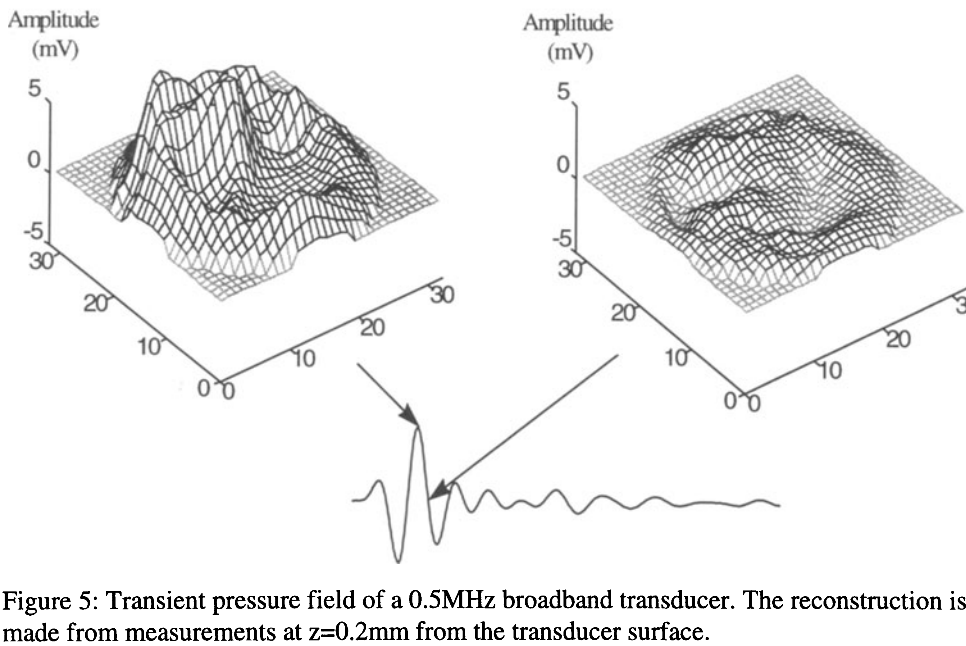

Figure 5: Transient pressure field of a 0.5MHz broadband transducer. The reconstruction is made from measurements at z=0.2mm from the transducer surface.

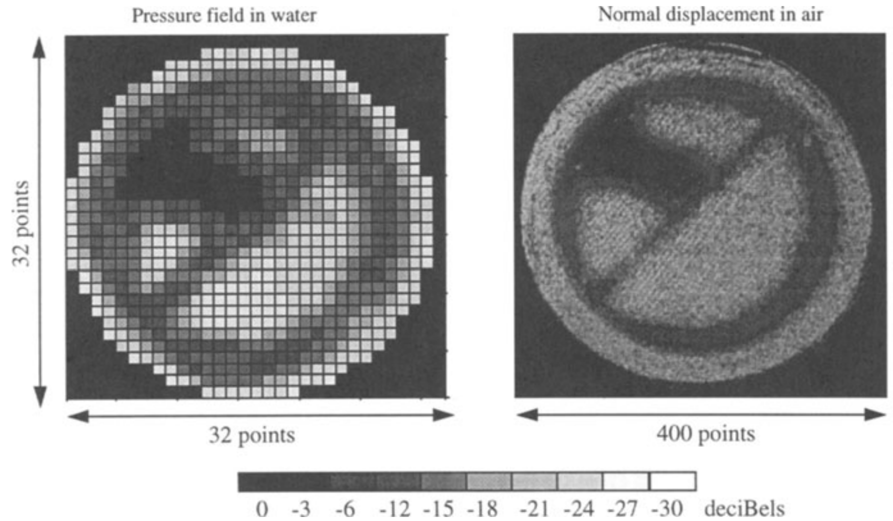

Figure 6: Cscans of the reconstructed pressure radiated at 0.2mm from the transducer surface in water and of the normal displacement in air.

CONCLUSION

Reconstruction of acoustic pressure field has been achieved using the interferometric detection method and a tomographic reconstruction algorithm. The advantage of the technique over reconstruction done from classical Schlieren system is the local measurement permitted by the laser beam and the ability to reconstruct time transient pressure fields. These characteristics have been demonstrated by reconstructing the transient pressure field at a distance of 0.2mm from the surface for two different transducers. The interferometric detection method is also able to give a quantitative measure of dilatational field inside transparent solids. This feature should allow the reconstruction of acoustic field radiated by contact transducer inside transparent solids, and may be used as a powerful model tool for several NDE applications.

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